Analysis of the In-Water and Sky Radiance Distribution Data Acquired During the Radyo Project

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LONG-TERM GOALS

My work involves experimentally investigating the interrelationships and variability of optical properties in the ocean and atmosphere. My goal is to define the variability of the optical properties, particularly those dealing with light scattering, and to improve the prediction capabilities of image and radiative transfer models used in the ocean. My near term ocean optics objectives have been: 1) to improve the measurement capability of measuring the in-water and above-water spectral radiance distribution and extending this capability to polarization, 2) to investigate the variability of the Point Spread Function (PSF) as it relates to the imaging properties of the ocean, and 3) to improve the characterization of the Bi-directional Reflectance Distribution Function (BRDF) of benthic surfaces in the ocean, and 4) to understand the capabilities and limitations of using radiative transfer to model the BRDF of particulate surfaces.

OBJECTIVES

The major objective of this research is to understand the downwelling spectral polarized radiance distribution, in the near surface of the ocean.

APPROACH

We have built, with ONR support (through the DURIP program) a camera system capable of measuring the polarization state of the downwelling radiance distribution. This instrument follows in the footsteps of other instruments we have developed (Voss and Liu, 1997) and uses a combination of 3-4 images of the radiance distribution to form this polarized radiance distribution. Because the downwelling radiance distribution is very dynamic, we need to have a system that will quickly make these images as matched as possible, so this required a completely new design.

The system we have designed uses 4 fisheye camera lenses with coherent fiber bundles behind each image. Each fisheye will have a polarizer in a different orientation. After the image is in the coherent fiber bundle, these bundles will be brought together and imaged on a CCD array camera, through a filter changer (for spectral information). Thus in a single image we will have 4 separate fisheye images of the scene, each with different polarization information. This instrument was used in the RaDyO program.

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In addition to the above system, we also built a similar system to capture the sky spectral polarized radiance distribution. The work of this proposal was to analyze the data acquired during the RaDyO program, and prepare articles for publication.

WORK COMPLETED

During the last year we continued investigating the polarized sky radiance data we had obtained with the RaDYO program. This sky data had already been used by one group to validate their radiative transfer model (Xu et al., 2011).

RESULTS

Our investigations into the sky radiance distribution were motiviated by our collaborations with Howard Schultz and Chris Zappa, other investigators in the RaDyO program. Their work involved using the polarized reflectance from the sea surface to determine the wave slope at very high spatial resolution (Pezzaniti, et al., 2009). One confounding factor in their work was that this polarized reflected light depended on the initial state of polarization of the skylight reflecting from the surface. As such they needed our measurements, or a good model of the polarization of the skylight, to determine these wave slopes. While we have many sky measurements in common with their measurement times, we did not have them all, so a simple model that described this polarization accurately would be very useful in their work.

So our first objective was to see if a simple model could be used to predict the polarized sky radiance distribution. An example of how well this worked is shown in Figure 1. This figure shows an example degree of polarization in the sky radiance distribution as measured in the upper left of the figure. The white blocked square is the area of the sky blocked by a sun occulter (to prevent direct solar radiance from entering the system), the incident solar beam will be behind this occulter. The maximum degree of polarization (DOP) is at a scattering angle of 90 degrees to the direct solar beam. In this, the maximum DOP is approximately 50% and is shaded green. On the top right is the model DOP, using a simple single scattering rayleigh atmosphere, but the DOP field is normalized by the maximum DOP in the sky data image. On the bottom left is the difference image between the data and model DOP (almost zero), while the bottom right has a histogram of this difference. As can be seen, the incident DOP can be predicted very well by single scattering, with the adjustment by the maximum DOP. For information, the maximum DOP predicted by the Rayleigh single scattering model would be 100%, so this adjustment to approximately 50% is very important. The accuracy is approximately +- 0.02-0.03 in the DOP.

The next stage would be to have a measurement of the maximum DOP, to be used to scale the model. In Figure 2 we show the relationship between maximum DOP and the aerosol optical depth (AOD). At low AOD, the maximum degree of polarization is approximately 70% at this wavelength. DOP decreases with increasing multiple scattering (towards the blue wavelengths with a clean Rayleigh atmosphere) and decreases with increasing AOD because aerosols, particularly dust, can strongly depolarize the atmospheric radiance. The two data sets acquired during RaDyO are shown and as can be seen there is a fairly regular decrease in maximum DOP with increasing AOD. What is not captured here is the confunding effects of AOD and solar zenith angle. As the solar zenith angle decreases (sun higher in the sky), the region where the max DOP would occur gets lower in the sky, towards the horizon. As this occurs, the pathlength through the atmosphere increases, hence the

opportunity for multiple scattering increases, and the max DOP decreases. So really we should be plotting maximum DOP vs both AOD and solar zenith angle.
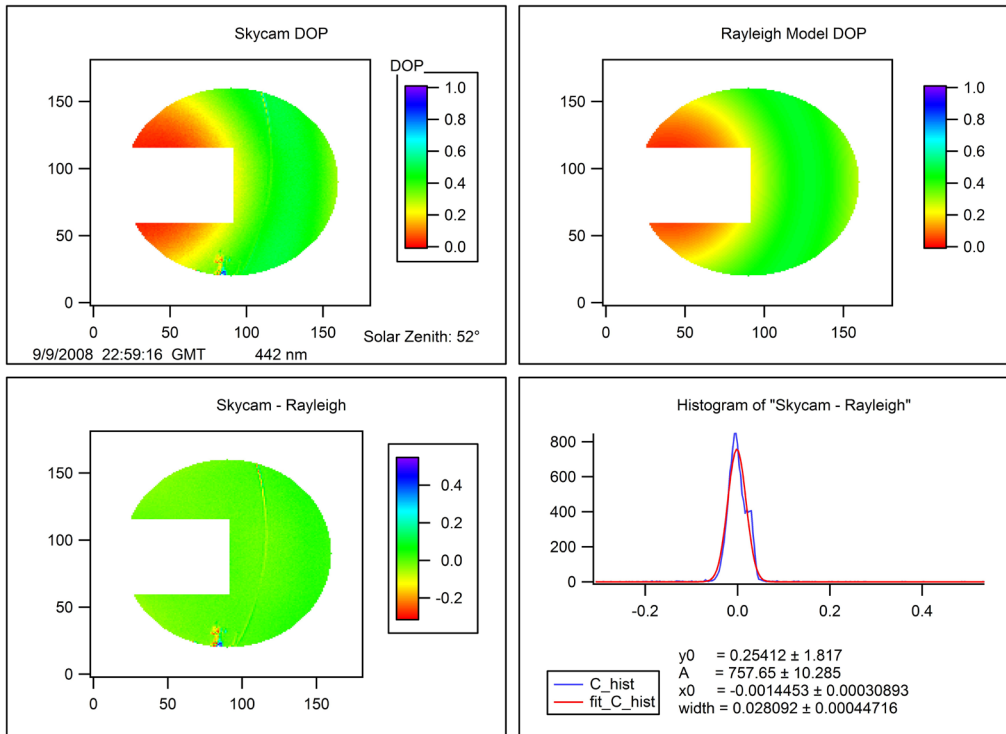

Figure 1) Example degree of polarization in sky radiance data (upper left), single scattering Rayleigh model degree of polarization (upper right) normalized by the maximum degree of polarization in the data, absolute difference between data and model(lower left), and finally histogram of absolute difference in degree of polarization in lower right. The model, when normalized by the maximum degree of polarization predicts the sky degree of polarization to within 0.03 (fully polarized is 1.00).
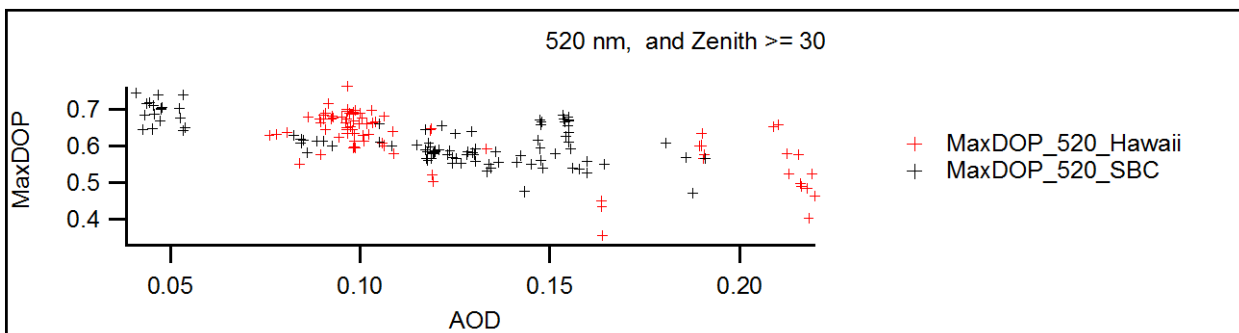

Figure 2) Maximum degree of polarizaiton (DOP) versus aerosol optical depth (AOD). This is for 520 nm and for data for which the solar zenith angle was greater than 30 degrees. The maximum degree of polarization decreases slightly as the AOD increases. The two data sets acquired during the RaDyO program are included, Hawaii and SBC, Santa Barbara Channel.
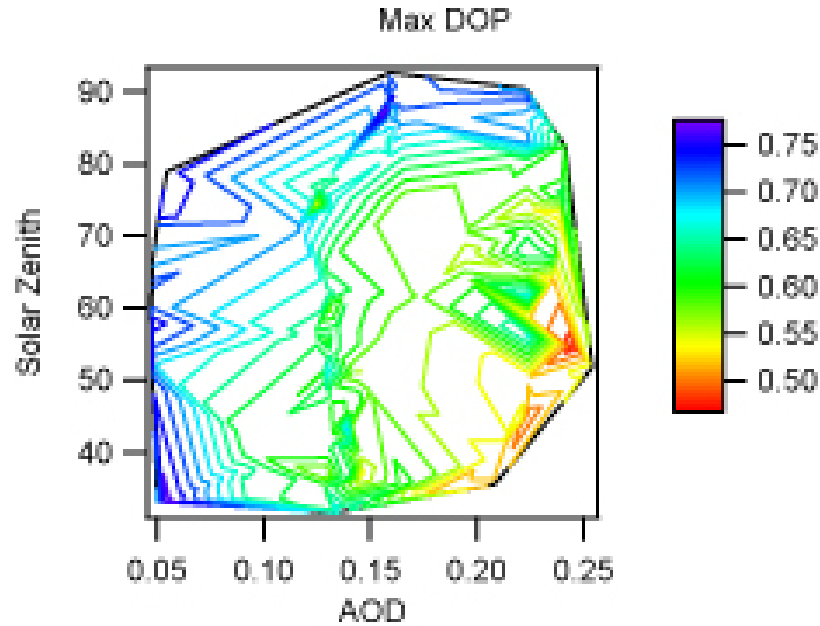
Figure 3) Relationship between Max DOP, Solar Zenith angle and AOD at 488 nm. One can see the effect that higher AOD decreases the maximum degree of polarization. There is also an effect, although less clear, that higher solar zenith angles will increase the Max DOP. Once the Max DOP is known, we can predict the skylight polarization field very well.

As we stand now, the model currently works well enough that it could be used by Howard Schultz for his efforts. Improvements would be useful to allow it to be accurate enough to be used as the polarized sky radiance input to models such as an expanded polarized Hydrolight. We have discussed this with Curt Mobley, who is developing a polarized version of Hydrolight. We have also found that polarization of the incoming sky light is very important in predicting the upwelling in-water polarized light field (Voss et al., 2011) and the downwelling in-water polarized light field (Bhandari et al., 2011).

One model we tested, and which improves the already good agreement between the model and data, is to use the Berry et al. (2004) model. This model includes multiple scattering effects, but unfortunately also requires data on the neutral points position in the sky, which is hidden inside the area of the sky blocked by our solar occulter. If more information were known (separation of Neutral points, maxDOP) a very accurate prediction could be made for the whole sky polarization pattern.

IMPACT/APPLICATIONS

The goal of the overall RadYO program is to understand how the radiance distribution is modified in the near surface, and what factors are important to this modification. Our work is showing how the near surface polarized radiance distribution is modified as it is transmitted through the air-sea interface and then into the water column. We are aiming for a simple sky radiance model that can be implemented into other in-water radiative transfer models.

RELATED PROJECTS

This project was part of the overall ONR RadYO program. We also have had DURIP support to build the instrument, fundamental to this work. Our work on the polarized radiance distribution is also related to our efforts with NASA funding to look at both the upwelling radiance distribution and the polarized upwelling radiance distribution.

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PUBLICATIONS

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